Quantum gravity and gravitational waves

(arXiv:1904.00384 and work in progress)
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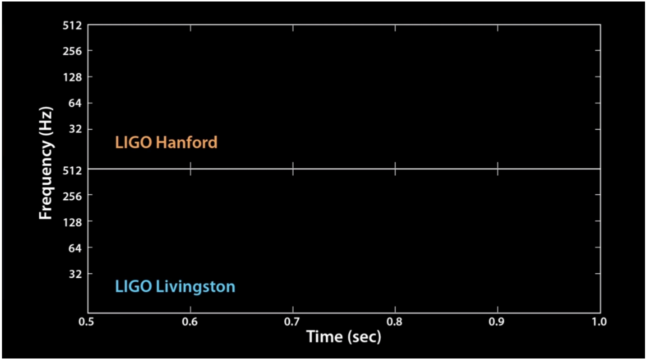
Gravitational waves (GWs)

Abbott et al., 2016



Theories beyond Einstein: any imprint in GW production or propagation?

Standard sirens: optical sources of GWs

EM luminosity distance: Flux = power per unit area

$$\mathrm{F} =: \frac{\mathrm{L}}{4\pi(d_L^{\mathrm{EM}})^2}\,, \qquad d_L^{\mathrm{EM}} = \frac{a_0^2}{a}\,r = (1+z)\int_0^z \frac{\mathrm{d}z'}{H(z')}$$

GW luminosity distance:

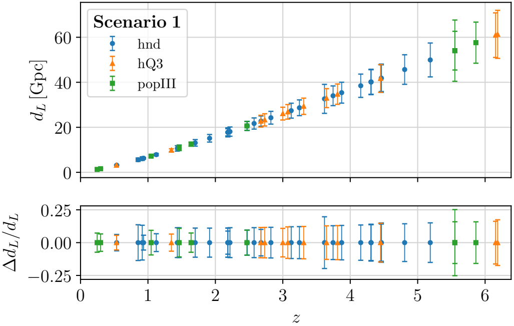
$$h \propto \frac{1}{d_L^{\mathrm{GW}}} \stackrel{\text{in GR}}{=} \frac{1}{d_L^{\mathrm{EM}}}$$

Known example (LIGO-Virgo/Fermi): BNS GW170817 / GRB170817A [Abbott et al. 2017]

Standard sirens @ LISA

LISA
CosWG-19-01

Belgacem et al. arXiv:1906.01593



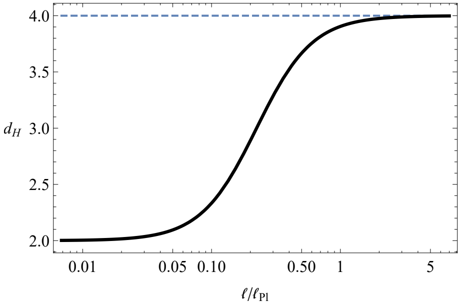
Quantum gravity (QG)

- Perturbative QG: effects important at high curvature/short distances. Homogeneous cosmology, only $\ell_{\rm Pl}$ and H available, corrections $(\ell_{\rm Pl}H)^n \overset{\rm today}{\sim} (10^{-60})^n, \qquad n=1,2,3,\dots$
- Non-perturbative QG effects, e.g., models with a third scale $L \gg \ell_{\rm Pl}$, quantum corrections $\sim \ell_{\rm Pl}^a H^b L^c$ with $a-b+c=0$, not all of them small [Bojowald, G.C., Tsujikawa, PRL 2011].

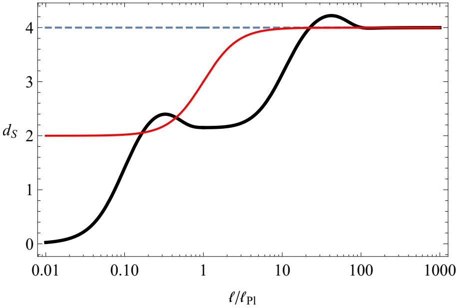
Dimensional flow

Universal non-perturbative effect in QG ['t Hooft 1993; Carlip 2009; G.C. PRL 2010; Carlip 2017]: running Hausdorff and spectral dimensions.

d_H: scaling of volume



d_S: scaling of dispersion rel.



Luminosity distance in QG

Local wave zone approximation $\omega r \gg 1$:

$$S = \frac{1}{2}\int \mathrm{d}\varrho(x)\, h_{ij}\mathcal{K}(\Box)\, h^{ij}, \qquad h_{ij} \sim \frac{1}{r^\Gamma} \to \frac{1}{(d_L^{\mathrm{EM}})^\Gamma}$$

$$\boxed{\boldsymbol{\Gamma = \frac{d_{\mathrm{H}}}{2} - \frac{d_{\mathrm{H}}^k}{d_{\mathrm{S}}}}\,, \qquad d_{\mathrm{S}} \neq 0}$$

Master formula

$$\boxed{\frac{d_L^{\rm GW}}{d_L^{\rm EM}} = 1 \pm |\gamma - 1| \left(\frac{d_L^{\rm EM}}{\ell_*}\right)^{\gamma-1}}$$

Master formula

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Very similar to models with extra dimensions [Deffayet, Menou 2007; Pardo et al. 2018; Abbott et al. 2018]

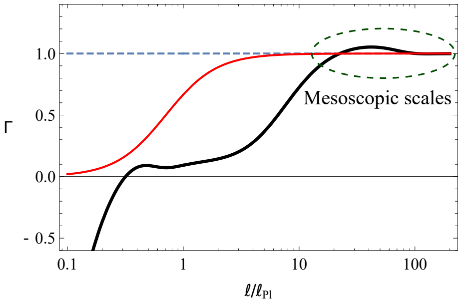
$$\frac{d_L^{\mathrm{GW}}}{d_L^{\mathrm{EM}}} = \left[1 + \left(\frac{d_L^{\mathrm{EM}}}{R_{\mathrm{c}}}\right)^{n_{\mathrm{c}}}\right]^{\frac{D-4}{2n_{\mathrm{c}}}}$$

UV geometry in QG (unobservable)

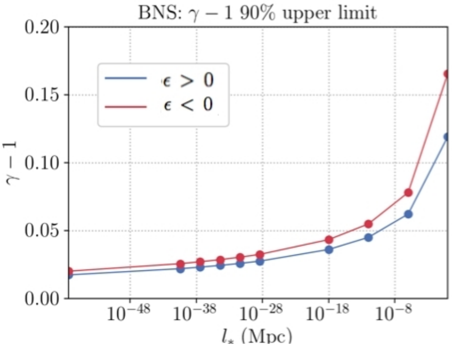
	$d_{\rm H}^{\rm UV}$	$d_{\rm H}^{k,\rm UV}$	$d_{\rm S}^{\rm UV}$	$\Gamma_{\rm UV}$	$\Gamma_{\rm meso} \gtrsim 1$
GFT/spin foams/LQG	2	4	$[1,4)$	$[-3,0)$	✓
Causal dynamical triangulations (phase C)	4	4	$3/2$	$-2/3$	
κ-Minkowski bicovariant ∇^2 (c.i.m.)	1	3	3	$-1/2$	
κ-Minkowski bicross-product ∇^2 (c.i.m.)	1	3	6	0	
Stelle gravity	4	4	2	0	
String theory (low-energy limit)	D	D	2	0	
Asymptotic safety	4	4	2	0	
Hořava–Lifshitz gravity	4	4	2	0	
κ-Minkowski relative-locality ∇^2 (c.i.m.)	1	3	$+\infty$	$1/2$	
κ-Minkowski bicovariant ∇^2 (o.m.)	4	3	3	1	
κ-Minkowski bicross-product ∇^2 (o.m.)	4	3	6	$3/2$	✓
κ-Minkowski relative-locality ∇^2 (o.m.)	4	3	$+\infty$	2	✓
Padmanabhan's non-local model	4	4	$+\infty$	2	✓

QG and standard sirens. 1

Standard sirens: BNS GW170817/GRB 170817A (LIGO-Virgo public data) and simulated SMBH, $d_L^{\rm EM} = 15.96$ Gpc, $z = 2$ (LISA catalogs). Detectable QG effect if $\gamma \gtrsim 1$, even when $\ell_* = O(\ell_{\rm Pl})$:



QG and standard sirens. 2



$$\boxed{\Gamma_{\rm meso} - 1 < 0.02}$$

QG and standard sirens. 3

Theories where $\gamma = \boldsymbol{\Gamma}_{\mathbf{meso}} \gtrsim 1$:

- Non-commutative κ-Minkowski spacetime
  $\Gamma_{\rm meso} \simeq 1 + \frac{5}{96\pi}\frac{\ell_{\rm Pl}^2}{\ell^2} \sim 1 + 10^{-120}$.
- Padmanabhan's model near BH horizon
  $\Gamma_{\rm meso} \simeq 1 + \frac{5\pi}{2}\frac{\ell_{\rm Pl}^2}{\ell^2} \sim 1 + 10^{-120}$.
- QGs with discrete pre-geometries: GFT, spin foams, LQG.
  $\Gamma_{\rm meso}$ strongly state dependent.

What to bring home

- We can and should ask more from our theories and push them to get phenomenology in GW astronomy (even negative one).
- Better to make this effort in fundamental theories (strings, quantum gravities, etc.) rather than in ad-hoc models.

ご清聴ありがとうございました

Thank you

Muchas gracias

Grazie

Muito obrigado

Kiitos paljon

Danke schön

Merçi beaucoup

Спасибо